SUDBURY ENVIRONMENTAL STUDY

1973 MICROBIOLOGY REPORT

PART B - INTENSIVE MONITORING PROGRAM

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SUMMARY

A preliminary microbiological study as part of the 1973 Intensive Monitoring Program was conducted to gain background information on populations of micro-organisms important in the aquatic ecosystem, and to determine their roles in the cycling of certain elements in four selected lakes in the Sudbury region. One pair of lakes (Nelson - Fairbanks) was selected for comparison on the basis of geographic location from the smelters (hence inputs of air-borne contaminants); the other pair (Nellie - Bassoon) varied in geological characteristics of their basins. One of the lakes in each pair was acidic (Nelson & Nellie), the other of neutral pH (Fairbanks & Bassoon).

Standard plate counts of heterotrophic bacteria (SPC) were higher at the surface of Fairbanks than Nelson in the summer only, while in the hypolimnion, the SPC was greater in Nelson than Fairbanks. No significant difference in SPC between sediments of these two lakes was observed.

Fungal populations in the water of these lakes showed no variation, but the greater populations of yeasts and moulds in the sediment of Nelson compared to Fairbanks L. may be associated with more favourable

conditions in Nelson L. sediment, i.e. higher content of organic matter and lower pH.

Levels of sulfate-reducers in both Nelson and Fairbanks lakes were low but higher counts in the hypolimnion (station #3) of Fairbanks coincided with anoxic conditions in the fall.

The higher concentrations of acidophilic autotrophic sulfur oxidizers in Nelson L. than Fairbanks would be favoured by the low pH of the former lake.

Both heterotrophic bacteria and fungi were more concentrated in water and sediment of Bassoon than Nellie L. Although yeasts and moulds would tolerate the low pH of Nellie L. well, they reached higher levels in neutral pH Bassoon, primarily due to a greater concentration of available organic matter in the latter lake.

Population of sulfur cycle bacteria were low in both Nellie & Bassoon. Sulfate-reducing bacteria were not detected in the sediment of either lake and counts were $<$ 10/100 ml in the water columns. Although counts of S oxidizers were relatively low, the levels of thiobacilli in Bassoon were significantly greater than in Nellie L.

Nitrifying bacteria were not detected in any of the lakes. Growth and activity of these sensitive bacteria would be inhibited by a low concentration of

NH_3 substrate, acid pH or presence of heavy metals, especially, Cu.

In all four of these oligotrophic lakes, the populations of all types of microorganisms representative of the carbon, nitrogen and sulfur cycles were much lower than those reported in the literature by other workers in lakes of greater nutrient status.

Fecal coliforms and fecal streptococci were not found in the study lakes which can be considered unpolluted from septic wastes. Bassoon L. with a median TC of 24/100 ml was the only lake positive for Enterobacteriaceae.

The relatively low populations of sulfur cycle bacteria in these lakes may be due to limiting factors, e.g. available nutrients, reduced inorganic sulfur compounds, pH, heavy metal toxicity.

Since the concentrations of Cu, Ni and Zn approached or exceeded total phosphorus levels in the lakes, there is cause for some concern over sub-lethal toxicity to natural aquatic microbes.

The comparatively low populations of autotrophic and heterotrophic microorganisms found in these ecosystems indicated a low microbial productivity and slow rate of nutrient recycling. Based on microbiological evidence, Bassoon L. appeared the least

dystrophic of all four selected lakes. Also differences in microbial populations between Nellie and Bassoon were more noticeable than differences in counts between the Nelson - Fairbanks pair.

Differences in counts for any parameter could not be explained solely due to acidity or heavy metal concentration. Nelson L. which has a lower pH and greater concentration of heavy metals than Fairbanks had greater populations of sulfur oxidizing bacteria and greater SPC in some cases, while Nellie Lake, also acidic and with higher concentrations of heavy metals than Bassoon, had relatively lower populations of microorganisms including the non-acidophilic sulfur bacteria.

INTRODUCTION:

In choosing lakes for the intensive water quality assessment programme, it was considered desirable to select two pairs of lakes, with each pair having one lake with a defunct fishery and the other with an exising fishery. It has been assumed that the two major variables (atmospheric input of contaminants and geological characteristics of the drainage basin) were probably the two key factors which would account for the differences in water chemistry and the fishery of lakes in the Sudbury area. On the basis of this assumption, the two pairs of lakes selected for investigation were Nelson-Fairbanks and Nellie-Bassoon.

Nelson and Fairbanks are both deep-water lakes with similar geological situations. Nelson's fishery has virtually disappeared, whereas Fairbanks Lake still supports a game fishery. Nelson covers an area of 780 acres and is situated approximately 18 air-miles due North of Sudbury. Fairbanks covers an area of 1240 acres and is located 18 air miles due West of Sudbury. The key variable for these lakes appears to be differences in loadings of

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atmospherically conveyed contaminants with the two lake being situated in different directions from Sudbury. Both are low-mineral or soft-water lakes.

Nellie and Bassoon Lakes are situated in the same direction, South-West of Sudbury at a distance of 35 and 30 air miles respectively so that the loadings of atmospherically conveyed contaminants should be a constant. Nellie has lost its fishery whereas Bassoon has retained populations of game fish species. The key variable for this pair of lakes appears to be related to geological considerations. Nellie is situated in lorraine quartzite with no glacial till, while Bassoon is situated in a basin of limestone and moderate deposits of glacial till.[1]

For more detailed information with respect to objectives and methodology for the 1973 Intensive Survey, the General Introduction and Methods sections of Part A - Lake Reclamation Study should be referred to. A detailed discussion of qualitative mycological data for Sudbury study lakes is also presented in Part A.

RESULTS AND DISCUSSION:

The data gathered for each of the four Intensive lakes was treated statistically (Mann-Whitney U-test)

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1. Personal communication, Nels Conroy, MOE
Sault Ste. Marie

to determine if there were differences in population levels for each parameter:

(a) between surface and bottom water stations,[1]

(b) between summer and fall seasons,

(c) between sampling stations within each lake.

The only lake where a variation between any of the three sampling stations occurred was Fairbanks, where only one parameter (SPC[2]) showed a significantly greater value in the hypolimnion at station 3 compared to station 1. However, there was no difference in levels of heterotrophic bacteria in the epilimnic waters between stations 1 and 3.

Total heterotrophic bacteria in Nelson Lake were found at significantly higher levels in the hypolimnion than the epilimnion during both seasons.

The surface vs depth variation was not observed for other microbial parameters in Nelson, while in Fairbanks at stations 2 and 3, a greater bacterial count was observed in the hypolimnion than in surface water in fall but not summer. This increased SPC at the bottom of stations 2 and 3 of Fairbanks coincided with a decline in D.O. in September-October at the same points. The increased bacterial biomass and metabolism could account for oxygen uptake and generation of CO_2 in the bottom. The free CO_2 concentration was highest

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1 - samples taken 1 m below surface and 1 m from bottom respectively

2 - SPC = Standard Plate Count, Aerobic Heterotrophic Bacteria.

in the hypolimnion of Fairbanks (11 mg/l) and Bassoon (10mg/l). The source of organic matter and nutrients causing the increased bacterial counts in the hypolimnion may be speculated upon in several ways. At the time of overturn in the fall, organic matter of terrestrial or aquatic origin in the surface could reach bottom. Even during summer thermal stratification, fall-out of heavier debris and settling to the bottom of the water column could occur. Stations 2 and 3 of Fairbanks were nearer shore than #1 and particulate organic matter from shore-line run-off after heavy rains could settle out directly in the cold waters of the hypolimnion. Another factor to be considered is the release of soluble organic matter and nutrients from the sediment to the water column which may contribute to greater microbial production in the hypolimnion.

Seasonal differences in populations of some parameters were also observed in both Nelson and Fairbanks Lakes. Although no seasonal differences in SPC were found between these lakes, yeast populations in the water column were significantly greater in summer than fall. Sulfur-oxidizing bacteria were more numerous in fall compared to summer. The decline in yeast concentration with the onset of colder water conditions was observed for all lakes. The yeast

genera found in the water may not have competed for soluble organics as well as the psychrophilic bacteria in colder water.

A quantitative comparison of microbial parameters between Nelson and Fairbanks Lakes in the epilimnion and hypolimnion for summer and fall is shown in Table I.

Median concentrations of aerobic heterotrophs in the water column were lower 1 meter below the surface than 1 m from the bottom in both lakes. The median SPC of 500 bacteria / 100 ml at the surface of Fairbanks in summer was significantly greater than the count in Nelson of only 52 / 100 ml. In autumn, no variation in SPC at surface between the lakes was observed. However, in the hypolimnion, the opposite was noted in summer where a greater SPC of 9100/ 100 ml was observed in Nelson than Fairbanks (1000/100 ml).

No significant differences in yeast populations were observed in the water column between the acidic Nelson or neutral Fairbanks Lakes. During the summer in the epilimnion, median yeast counts of 15 and 10 c.f.u. (colony forming units) per 100 ml were recorded for Nelson and Fairbanks Lakes, and in the hypolimnion, 17 and 46 c.f.u. / 100 ml respectively.

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TABLE I Quantitative comparison of microbial parameters in water according to depth and season between NELSON and FAIRBANKS LAKES.

Median count per 100 ml H_2O (SURFACE)

PARAMETER	SUMMER		FALL	
	NELSON	FAIRBANKS	NELSON	FAIRBANKS
SPC	52	500*	180	380
Yeasts	15	10	9	6
Moulds	8	10	9	6
SO_4-Reducers	-	-	7	<3
Thiobacillus (I)[1]	4	<3	170	<3*
Thiobacillus (II)[2]	<3	<3	85	15*
Nitrifiers	<3	<3	<3	<3
TC (Total Coliform)	-	-	<4	<4
FC (Fecal Coliform)	-	-	<4	<4
FS (Fecal Streptococcus)	-	-	<4	<4

Median count per 100 ml H_2O (DEPTH)

PARAMETER	SUMMER		FALL	
	NELSON	FAIRBANKS	NELSON	FAIRBANKS
SPC	9100	1000*	3100	8700
Yeasts	17	46	5	51
Moulds	2	2	2	4
SO_4-Reducers	-	-	5	<3
Thiobacillus (I)	17	<3*	390	<3*
Thiobacillus (II)	<3	<3	330	15*

1 - acidophilic S oxidizers
2 - non-acidophilic S oxidizers
* - Significant difference

TABLE II   A quantitative comparison of various microbial parameters in sediments between NELSON and FAIRBANKS LAKES.

Median count per gram sediment (wet wt.)

PARAMETER	NELSON	FAIRBANKS
SPC	29,000	120,000
Yeasts	100	2*
Moulds[1]	1500	60
SO_4-Reducers	<30	<30
Thiobacillus (I)	75	10*
Thiobacillus (II)	<3	7
Nitrifier	<30	<30

1 - Mould data for Nelson Lake based on only 1 piece of information. Hence insufficient for comparison.

TABLE III Quantitative comparison of various microbial parameters in water at two depths between NELLIE and BASSOON LAKES.

Median count per 100 ml H_2O

PARAMETER	SURFACE		DEPTH	
	NELLIE	BASSOON	NELLIE	BASSOON
SPC	330	1200*	1200	405* (p=.05)
Yeasts	30	52*	5	19*
Moulds	6	16*	2	2
SO_4-Reducers	<3	9* (p=.05)	-	-
Thiobacillus (I)	<3	4	<3	11* (p=.05)
Thiobacillus (II)	<3	13* (p=.05)	<3	21* (p=.05)
Nitrifiers	<3	<3	-	-
TC (Total Coliform)	<4	24* (p=.1)	-	-
FC (Fecal Coliform)	<4	<4	-	-
FS (Fecal Streptococcus)	<4	<4	-	-

TABLE IV A quantitative comparison of various microbial parameters in sediments between NELLIE and BASSOON LAKES.

Median count per gram sediment (wet wt.)

PARAMETER	NELLIE	BASSOON
SPC	8600	240,000*
Yeasts	<2	2
Moulds	49	270
SO_4-Reducers	<30	<30
Thiobacillus (I)	<30	23
Thiobacillus (II)	5	110* (p=0.1)
Nitrifiers	<30	<30
TC (Total Coliform)	-	<100
FC (Fecal Coliform)	-	<100
FS (Fecal Streptococcus)	-	<100

TABLE V INTENSIVE LAKE MONITORING DATA (SEPTEMBER 1973)

PARAMETER	FAIRBANKS surface	FAIRBANKS bottom	NELSON surface	NELSON bottom	BASSOON surface	BASSOON bottom	NELLIE surface	NELLIE bottom
pH	7.7	6.7	5.6	5.7	8.1	6.7	4.5	4.8
Alkalinity	14	16	2.0	3.5	24	23	0	1
Ca	8	8	5	6	13	15	4	3
Mg	2	2	1	2	3	2	1	2
Conductivity	65	67	45	47	93	95	50	50
K	1.1	1.1	1.1	1.1	1.1	1.2	0.9	0.8
Free CO_2	<0.5	11	1.7	7.4	<1.0	10	5.1	5.1
DO	11.9	0.4	11	3.0	11	1.3	11	10.4
Total P	.018	.016	.013	.021	.011	.009	.008	.004
Free NH_3	.02	.01	.02	.04	.01	.06	.03	<.01
Total N	.21	.14	.12	.15	.35	.41	.10	.12
NO_3-N	<.01	.02	<.01	.14	<.01	.19	.16	.16
SO_4	15	15	15	15	17	17	14.0	14.0
Chlorophyll a	1.20	-	0.53	-	2.15	-	0.34	-
Sediment pH	7.0		6.0		6.5		5.0	
Sediment % loss ignition	7.7		23		42		17	
Heavy Metals (ppm)								
Ni	.005		.019		.014		.028	
Cu	.003		.019		.013		.013	
Zn	.006		.021		.014		.028	

Information Courtesy L. Maki, Biologist, MOE, Sault Ste. Marie

Mould counts in both lakes were relatively low throughout the sampling period, counts at the surface averaging 6 - 10 c.f.u. / 100 ml and at the bottom 2 - 4 c.f.u. / 100 ml. However, in the sediment, (Table II), moulds were more concentrated, a count of 1500 c.f.u. / gram found in one particular sample from Nelson Lake and 60/g in the less acidic Fairbanks Lake sediment. A median yeast count of 100 per gram in Nelson Lake sediment was significantly greater than only 2/g in Fairbanks Lake. Factors responsible for this difference are unknown at present. Lower sediment pH and greater availability of organic matter and nutrients, and presence of oxygen would all favour fungal growth. Anoxic conditions, detrimental to fungal growth were found in the hypolimnion of Fairbanks Lake in September.

The greater populations of fungi in the sediment of Nelson than Fairbanks may be associated with the higher content of organic matter in the former lake sediment (23% loss on ignition) compared to 7.7% loss in the latter.

Sulphate-reducers (Desulfovibrio sp.) were not detected in the sediments of either lake in summer (<30/g) but no data was available for fall. Levels of these anaerobic bacteria were very low in the water column of both lakes,

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averaging only <3 - 7 / 100 ml throughout most of the survey period. The sulfate reducing bacteria appear to be good indicators of anaerobic conditions and the highest count in Nelson and Fairbanks Lakes was observed in October at the anoxic bottom of station 3 (Fairbanks) where the count reached 160 / 100 ml.

During summer, the distribution of both acidophilic sulfur oxidizing autotrophic bacteria (Thiobacillus thio-oxidans) and the non-acidophilic T. thioparus group at the surface of both lakes was only <3 & 4 / 100 ml. In the hypolimnion, the acidophilic S oxidizers were at a higher level in Nelson (17/100 ml) than Fairbanks (<3/100 ml), while the non-acidophiles were distributed at low concentrations (<3/100 ml) in both lakes.

During the autumn, populations of both groups of sulfur oxidizers were significantly higher in the water column of Nelson than Fairbanks. Counts of T. thiooxidans (I) and T. thioparus (II) at the surface of Nelson were 170 and 85/ 100 ml respectively compared to <3 and 15 / 100 ml respectively for Fairbanks. At the bottom, counts of (I) and (II) for Nelson were 390 and 330 / 100 ml respectively compared to <3 and 15/100 ml for Fairbanks. The autotrophic sulfur oxidizers were more numerous in fall than summer. In lake

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sediment, populations of (I) were greater in Nelson (75/g) than Fairbanks (10/g), while no significant difference was observed in counts of (II) between Nelson (<3/g) and Fairbanks (7/g). The higher counts of acidophilic sulfur oxidizers observed in Nelson Lake water and sediment would be favoured by the acidic condition of the lake, and possibly by release of more reduced inorganic S compounds from the more organic rich Nelson Lake sediment.

The autotrophic ammonia-oxidizing bacteria (Nitrosomonas sp.) were not detected in water column or sediment of either lake. In view of the low concentrations of various forms of N in these lakes (see Table V), the energy sources for the nitrifying bacteria are apparently growth limiting. As these bacteria are acutely sensitive to acidity and heavy metals, the growth-inhibiting properties of low pH and Cu, Ni and Zn to nitrifiers should also be considered.

In Nellie and Bassoon Lakes, no variation in any parameter was observed within each lake between stations. In Nellie Lake, surface vs. depth and summer vs. fall variation was not observed for any parameter. In Bassoon Lake, only the fungi showed a significantly higher distribution at surface compared to depth of the water column. Surface counts of 51 c.f.u. yeasts and 16 c.f.u. moulds / 100 ml and depth counts of 19 yeasts and 2 moulds per 100 ml were observed.

In the 1973 study, the TPC was significantly greater at the surface of Bassoon (1200/100 ml) than Nellie (330/100 ml) (Table III). In the hypolimnion, the median TPC of 405/100 ml in Bassoon was less than that in Nellie (1200/100 ml). The population of heterotrophic bacteria (TPC) in the sediment was greater in Bassoon (240,000/g) than Nellie (8600/g) (Table IV).

The distribution of yeasts in the water column was greater in Bassoon than Nellie Lake, averaging 52 and 19/100 ml at surface and depth in the former; only 30 and 5/100 ml at surface and depth in the latter. Yeast counts were low (<2 - 2 /g) in sediment of both lakes, while moulds reached 49 and 270 c.f.u. /g. in sediment from Nellie and Bassoon repectively. As with the total yeast count, the mould density was greater at the surface of Bassoon (16 c.f.u./100 ml) than Nellie (6/100 ml). However, no difference in mould counts between lakes was found in the hypolimnion where levels were low (2/100 ml) in both cases.

It is apparent from the results that both groups of heterotrophs (fungi and bacteria) were more concentrated in the surface water and sediment of Bassoon than Nellie Lake. Even in the hypolimnion, yeasts were more numerous in Bassoon than Nellie. Although yeasts and moulds would

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have a growth advantage due to low pH in Nellie, they may reach higher levels in the neutral pH Bassoon Lake because of a greater concentration of available organic matter and nutrients in Bassoon than Nellie. As primary productivity was greater in Bassoon than Nellie, the former lake would conceivably support a greater population of the decompser group of heterotrophic microorganisms in the ecosystem.

Populations of sulfur cycle bacteria were low in both of these oligotrophic lakes. Sulfate-reducers were undetected in lake sediment (<30/g) of both lakes and the water column of Nellie but were detected in Bassoon lake water (9/100 ml).

The non-acidophilic sulfur oxidizers were greater in the surface water of Bassoon (13/100 ml) than Nellie (<3) while at the depth, both groups (I) and (II) were greater in Bassoon (11 and 21 / 100 ml) than Nellie (<3/100 ml). In sediment, only the non-acidophilic thiobacilli (II) were significantly different between lakes. (Bassoon = 110/g and Nellie = 5/g). As in Nelson and Fairbanks, nitrifiers and fecal parameters were not detected in either Nellie or Bassoon Lakes, but a relatively low population of total coliforms occurred in Bassoon (24/100 ml).

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Other workers have reported that total bacterial counts obtained in eutrophic waters and sediments were several fold greater than those obtained for oligotrophic lakes. In Lake Windermere (U.K.), total heterotrophic counts of 85,000/100 ml rose to 1,200,000/100 ml after a heavy rainfall (Taylor, 1942). The increased count after rainfall was attributed primarily to a stimulation of the growth of the indigenous population by nutrients carried in and to a lesser degree by washed-in bacterial cells. Bennett (1969) related the growth response of Acinetobacter sp. to eutrophic conditions in Lake Ontario.

In a eutrophic lake of the Lake District, U.K., Collins and Willoughby (1962) found bacterial populations of 60,000 - 600,000/100 ml and fungi (yeasts and moulds) at 30 - 3,000/100 ml. Following heavy rains, numbers rose several times in excess of these values.

The total concentration of bacteria in lake water is closely related to the nature and availability of organic matter and inorganic nutrients for microorganisms. Abdirov (1968) pointed out that the number of bacteria observed in a water body at any point in time is the resulting magnitude of the rate of bacterial multiplication, their consumption by zooplankton and their death. He estimated a generation

time of 36 hours for aquatic heterotrophic bacteria in cold water, while in summer the rate of reproduction in warmer water was 7 - 8 hours. He found higher counts of heterotrophs in Lake Karateren in spring (38,000/100 ml) compared to winter (10,000/100 ml). In muds of this eutrophic Russian freshwater lake, the total aerobic bacteria averaged 1.0×10^6/g, yeasts (10^3/g) and SO_4 reducers (10^3/g).

In the four oligotrophic soft-water lakes studied in the Sudbury area, the levels of all types of microorganisms in water and sediment were much lower than those found by other workers in lakes of higher nutrient status.

Median standard bacterial plate counts in the water columns of the four Sudbury Intensive Lakes varied from 52 (Nelson) to 1200/100 ml (Bassoon) at the surface. These counts were somewhat lower than mean plate counts for surface water in two oligotrophic lakes surveyed in 1973 near Huntsville, Ontario, Harp and Jerry Lakes (2260 and 2000 per 100 ml respectively)*. Also low counts of total coliforms were detected in the oligotrophic Huntsville lakes, but not in the four Sudbury lakes, except for Bassoon (24/100 ml). The fecal coliforms and streptococci were not

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* Personal communication, P. Milley, Microbiology Section

found in the Sudbury lakes which can be considered unpolluted from septic wastes. Future work in 1974 may indicate possible reasons for the absence of the family Enterobacteriaceae in the Sudbury lakes.

Nellie, Nelson, Bassoon and Fairbanks Lakes are all truly oligotrophic with total N concentrations of only 0.1 - 0.2 mg/l, total P (.004 - .02 mg/l) and K (1.0 mg/l). In addition to these nutrient elements, organic carbon also occurred at low concentrations in the lake water. Thus, low counts of heterotrophic bacteria and fungi may be explained in part by the paucity of available nutrient and energy sources for growth. The higher populations of heterotrophic bacteria observed in the hypolimnion of Nelson and Fairbanks Lakes compared to surface waters, is a phenomenon yet unknown. The depressed DO and high CO_2 concentration observed in the hypolimnion, is likely a result of increased O_2 uptake by higher numbers of bacteria. T.O.C., especially soluble organic carbon, should be monitored in future studies, as release of soluble organics and nutrients from sediments may stimulate increased microbial activity in the hypolimnion.

Although these lakes in the Sudbury area are being continuously subjected to inputs of sulfur compounds, the

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populations of sulfur cycle bacteria in these lakes was not considered high. Although carbon, i.e. CO_2 would not be limiting for the autotrophic sulfur bacteria, forms of reduced sulfur appear to be limiting as an energy source.

Sulphate reducing activity to generate substrate for thiobacilli was virtually nonexistent as estimated by nondetectable levels of sulfate-reducers in water and sediment. Nutrient elements, e.g. N, P, K, would be somewhat limiting for the sulfur oxidizers, and for Desulfovibrio spp. as well. Conditions necessary for development of sulfate-reducers, e.g. adequate supply of a soluble carbon source (organic acids, etc.), anaerobiosis and netral pH, were limiting in the aquatic ecosystems to varying degrees. Besides, SO_4 concentrations in the water of 14-17 mg/l would not allow for an excessive build-up of sulfate reducing bacteria.

The concentrations of heavy metals (Cu, Ni, Zn) in the water of these lakes although considerably lower than those metal concentrations found in the Reclamation Lakes, varied from approximately .005 ppm in Fairbanks to .028 ppm in Nellie Lake. These metal concentrations approached or exceeded total phosphorus levels in some cases.

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It is unknown at present from qualitative data if the existing concentration of heavy metals would have any far-reaching detrimental effects on normal aquatic bacteria. In the acidic lakes, Nelson and Nellie, the heavy metal toxicity would be more acute than in the two neutral pH lakes. Sub-lethal effects, i.e. heavy metal inhibition of specific biochemical processes of heterotrophic bacteria may occur and sensitive bacteria, e.g. nitrifiers are inhibited by Cu^{+2} at concentrations as low as .05 mg/l (Loveless and Painter, 1968). A recent article published in "Science", January 1974 indicated that N_2 fixation by blue-green algae in surface lake water was inhibited by Cu^{+2} in the ppb range.

Kalabina et al (1944) observed that processes of nitrification and oxidation of organic matter in polluted river water were inhibited by doses of 0.5 mg/l Cu^{+2} and greater. The higher calcium ion content of Bassoon Lake would be a mitigating factor in reducing metal ion toxicity to microorganisms in this lake, which was apparently the least dystrophic of the four oligotrophic lakes under study.

Qualitatively and quantitatively the lakes studied in the intensive survey seem to have a normal component of

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yeast and heterotrophic bacterial flora for a freshwater oligotrophic lake. Some discrepancies were observed i.e. higher bacterial counts in the hypolimnion of Nelson, Fairbanks and Nellie, than would be expected in water with a low supply of nutrients and C sources as well as the absence of the Enterobacteriaceae group.

The relatively low populations of autotrophic and heterotrophic microorganisms found in these lake ecosystems indicated a low overall microbial productivity.

Further work hopefully will elucidate the rates of microbial activities in production of biomass and release of nutrients as food sources for higher trophic levels of the food chain.

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APPENDIX TABLE I NELSON LAKE (α)

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	T.thioparus	Nitrifier NH_3 oxid.
June 22	1 - Surface	130	-	-	-	21	-	N.D. *	4	< 3	-
	Depth	2,300	-	-	-	15	-	"	23	4	-
	Sediment	-	-	-	-	-	-	"	11	< 3	-
	2 - Surface	80	-	-	-	16	-	"	< 3	< 3	-
	Depth	4,800	-	-	-	17	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	43	< 3	-
	3 - Surface	52	-	-	-	18	-	"	4	< 3	-
	Depth	2,000	-	-	-	12	-	"	23	< 3	-
	Sediment	-	-	-	-	-	-	"	23	< 3	-
June 23	1 - Surface	52	-	-	-	-	-	N.D.	9	< 3	-
	Depth	> 15,000	-	-	-	-	-	"	11	< 3	-
	Sediment		-	-	-	-	-	"	9	< 3	-
	2 - Surface	80	-	-	-	-	-		7	< 3	-
	Depth	> 15,000	-	-	-	-	-	"	9	< 3	-
	Sediment		-	-	-	-	-	"	75	< 3	-
	3 - Surface	32	-	-	-	-	-	"	< 3	< 3	-
	Depth	> 15,000	-	-	-	-	-	"	23	< 3	-
	Sediment		-	-	-	-	-	"	73	< 3	-
July 25	1 - Surface	20	-	-	-	64	6	N.D.	-	-	-
	Depth	33,000	-	-	-	10	14	"	-	-	-
	2 - Surface	< 4	-	-	-	6	2	"	-	-	-
	Depth	< 100	-	-	-	8	2	"	-	-	-
	3 - Surface	12	-	-	-	2	18	"	-	-	-
	Depth	1,700	-	-	-	-	-	"	-	-	-

* NOT DETECTED (media pH of 5.5 too low to support growth)

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NELSON LAKE

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	SULFUR OXIDIZERS T.thioparus	Nitrifier NH_3 oxid.
July 26	1 - Surface	280	-	-	-	170	10	-	-	-	-
	Depth	20,000	-	-	-	210	8	-	-	-	-
	Sediment	-	-	-	-	-	-	-	70	2,400	< 30
	2 - Surface	40	-	-	-	50	-	-	-	-	-
	Depth	12,000	-	-	-	100	-	-	-	-	-
	Sediment	2,000	-	-	-	-	-	-	230	430	-
	3 - Surface	2,000	-	-	-	10	-	-	-	-	-
	Depth	6,100	-	-	-	26	-	-	-	-	-
	Sediment	4,000	-	-	-	-	-	-	-	-	-
Sept. 12	1 - Surface	120	< 4	< 4	< 4	6	8	4	47	70	9
	Depth	620	< 4	< 4	< 4	6	< 2	< 3	550	100	-
	Sediment	69,000	-	-	-	100	-	< 30	1,100	1,100	< 30
	2 - Surface	36	< 4	< 4	< 4	14	6	< 3	100	100	< 3
	Depth	7,100	< 4	< 4	< 4	56	2	< 3	550	550	-
	Sediment	29,000	-	-	-	100	-	< 30	1,100	1,100	-
	3 - Surface	140	< 4	< 4	< 4	12	10	15	500	60	< 3
	Depth	3,100	< 4	< 4	< 4	100	4	9	150	550	-
	Sediment	37,000	-	-	-	200	2,000	< 30	1,100	1,100	-
Oct. 6	1 - Surface	220	< 4	< 4	< 4	< 2	6	-	-	-	-
Oct. 16	1 - Surface	2,400	28	< 4	< 4	30	12	23	230	100	-
	Depth	4,200	68	< 4	< 4	4	< 4	93	230	100	-
Oct. 23	1 - Surface	250	< 4	< 4	< 4	6	12	-	-	-	-
	Depth	400	< 4	< 4	< 4	< 2	4	-	-	-	-

APPENDIX TABLE II

FAIRBANKS LAKE (β)

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	T.thioparus	Nitrifier NH_3 oxid.
June 20	1 - Surface	100	-	-	-	-	-	N.D.	< 3	< 3	-
	Depth	1,600	-	-	-	-	-	"	< 3	< 3	-
	Sediment	-	-	-	-	-	-	"	< 3	< 3	-
	2 - Surface	240	-	-	-	-	-	"	< 3	< 3	-
	Depth	250	-	-	-	-	-	"	< 3	< 3	-
	Sediment	-	-	-	-	-	-	"	< 3	< 3	-
	3 - Surface	640	-	-	-	-	-	"	< 3	< 3	-
	Depth	160	-	-	-	-	-	"	< 3	< 3	-
	Sediment	-	-	-	-	-	-	"	< 3	< 3	-
June 21	1 - Surface	140	-	-	-	8	-	N.D.	< 3	< 3	-
	Depth	390	-	-	-	18	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	23	< 3	-
	2 - Surface	250	-	-	-	12	-	"	< 3	< 3	-
	Depth	280	-	-	-	14	-	"	< 3	< 3	-
	Sediment	-	-	-	-	-	-	"	4	< 3	-
	3 - Surface	160	-	-	-	8	-	"	< 3	< 3	-
	Depth	110	-	-	-	30	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	9	< 3	-
July 27	1 - Surface	360	-	-	-	< 2	2	N.D.	-	-	-
	Depth	1,700	-	-	-	62	< 2	"	-	-	-
	Sediment	-	-	-	-	-	-	"	< 3	4	-
	2 - Surface	6,000	-	-	-	22	10	"	-	-	-
	Depth	200	-	-	-	74	2	"	-	-	-
	Sediment	-	-	-	-	-	-	"	< 3	9	-
	3 - Surface	1,000	-	-	-	8	40	"	-	-	-
	Depth	3,800	-	-	-	10	4	"	-	-	-
	Sediment	-	-	-	-	-	-	"	-	-	-

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FAIRBANKS LAKE

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	T. thioparus	Nitrifie NH_3 oxid
July 28	1 - Surface	10,000	-	-	-	50	10	-	-	-	-
	Depth	10,000	-	-	-	68	-	-	-	-	-
	Sediment	200,000	-	-	-	-	-	-	-	-	-
	2 - Surface	7,200	-	-	-	28	-	-	-	-	-
	Depth	2,700	-	-	-	26	-	-	-	-	-
	Sediment	400,000	-	-	-	-	-	-	-	-	-
	3 - Surface	5,800	-	-	-	50	-	-	-	-	-
	Depth	5,300	-	-	-	28	-	-	-	-	-
	Sediment	-	-	-	-	-	-	-	-	-	-
Sept. 14	1 - Surface	550	< 4	< 4	< 4	16	4	< 3	< 3	3	< 3
	Depth	460	< 4	< 4	8	100	4	< 3	< 3	15	-
	Sediment	120,000	-	-	-	38	60	< 30	< 30	930	< 30
	2 - Surface	380	< 4	< 4	< 4	6	6	< 3	< 3	15	< 3
	Depth	48,000	< 4	< 4	< 4	150	6	< 3	< 3	3	-
	Sediment	9,700	-	-	-	2	6	< 30	< 30	930	< 30
	3 - Surface	200	< 4	< 4	12	2	2	< 3	< 3	3	< 3
	Depth	37,000	< 4	< 4	< 4	240	4	< 3	< 3	11	-
	Sediment	12,000	-	-	-	11	78	< 30	< 30	< 30	< 30
Oct. 6	1 - Surface	100	< 4	< 4	4	4	4	-	-	-	-
Oct. 19	1 - Surface	570	< 4	< 4	< 4	12	16	< 3	< 3	43	< 3
	Depth	530	4	< 4	< 4	< 2	< 2	< 3	< 3	24	< 3
	3 - Surface	3,400	< 4	< 4	< 4	6	14	4	< 3	93	< 3
	Depth	17,000	< 4	< 4	< 4	< 2	4	160	< 3	93	-
Oct. 23	1 - Surface	130	-	-	-	2	8	-	-	-	-
	Depth	110	-	-	-	< 2	8	-	-	-	-

APPENDIX TABLE III

NELLIE LAKE (Y)

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	T.thioparus	Nitrifier NH_3 oxid.
June 28	1 - Surface	-	-	-	-	-	-	N.D.	< 3	< 3	-
	Depth	-	-	-	-	-	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	23	< 3	-
	2 - Surface	-	-	-	-	-	-	"	< 3	< 3	-
	Depth	-	-	-	-	-	-	"	23	< 3	-
	Sediment	-	-	-	-	-	-	"	< 3	< 3	-
	3 - Surface	-	-	-	-	-	-	"	< 3	< 3	-
	Depth	-	-	-	-	-	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	4	< 3	-
June 29	1 - Surface	-	-	-	-	-	-	N.D.	< 3	< 3	-
	Depth	-	-	-	-	-	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	9	< 3	-
	2 - Surface	-	-	-	-	-	-	"	< 3	< 3	-
	Depth	-	-	-	-	-	-	"	< 3	< 3	-
	Sediment	-	-	-	-	-	-	"	15	< 3	-
	3 - Surface	-	-	-	-	-	-	"	4	< 3	-
	Depth	-	-	-	-	-	-	"	< 3	< 3	-
	Sediment	-	-	-	-	-	-	"	9	< 3	-
July 31	1 - Surface	9,100	-	-	-	88	16	N.D.	< 3	< 3	-
	Depth	1,100	-	-	-	-	-	"	4	46	-
	2 - Surface	800	-	-	-	-	-	"	< 3	24	-
	Depth	20,000	-	-	-	-	-	"	4	< 3	-
	3 - Surface	700	-	-	-	-	-	"	9	110	-
	Depth	14,000	-	-	-	-	-	"	< 3	< 3	-

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NELLIE LAKE

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS		Nitrifier NH_3 oxid.
									Thiobacillus thiooxidans	T.thioparus	
July 31	1 - Sediment	5,000	-	-	-	-	-	N.D.	240	9	-
	2 - Sediment	2,700	-	-	-	-	-	"	1,100	43	-
	3 - Sediment	5,100	-	-	-	-	-	"	240	9	-
Sept. 6	1 - Surface	32	16	1	28	-	-	< 3	< 3	9	< 3
	Depth	-	-	-	-	-	-	< 3	< 3	-	-
	3 - Surface	340	40	12	44	-	-	< 3	< 3	9	< 3
	Depth	-	-	-	-	-	-	< 3	< 3	-	-
Sept. 20	1 - Surface	390	-	-	-	46	10	-	-	-	-
	Depth	640	-	-	-	2	< 2	-	-	-	-
	Sediment	22,000	-	-	-	4	110	< 30	< 30	< 30	< 30
	2 - Surface	430	-	-	-	4	< 2	-	-	-	-
	Depth	6,900	-	-	-	4	4	-	-	-	-
	Sediment	12,000	-	-	-	0	15	< 30	< 30	< 30	< 30
	3 - Surface	190	-	-	-	2	< 2	-	-	-	-
	Depth	520	-	-	-	6	< 2	-	-	-	-
	Sediment	12,000	-	-	-	4	49	< 30	< 30	< 30	< 30
Oct. 24	1 - Surface	110	< 4	< 4	< 4	36	6	< 3	< 3	< 3	< 3
	Depth	1,200	< 4	< 4	< 4	12	2	< 3	< 3	< 3	< 3
	2 - Surface	120	< 4	< 4	< 4	30	8	< 3	< 3	< 3	< 3
	Depth	4,600	< 4	< 4	< 4	10	2	< 3	< 3	< 3	< 3
Nov. 7	2 - Surface	320	-	-	-	< 2	4	< 3	< 3	4	-
	Depth	80	-	-	-	2	8	< 3	< 3	4	-

APPENDIX TABLE IV

BASSOON LAKE (є)

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	SULFUR OXIDIZERS T.thioparus	Nitrifier NH_3 oxid.
June 26	#1 - Surface	330	-	-	-	32	-	N.D.*	< 3	< 3	-
	Depth	250	-	-	-	26	-	"	23	< 3	-
	#2 - Surface	190	-	-	-	14	-	"	< 3	< 3	-
	Depth	160	-	-	-	50	-	"	23	< 3	-
	#3 - Surface	590	-	-	-	51	-	"	< 3	< 3	-
	Depth	580	-	-	-	19	-	"	23	< 3	-
June 27	#1 - Surface	760	-	-	-	-	-	N.D.	7	< 3	-
	Depth	312	-	-	-	-	-	"	4	< 3	-
	Sediment	-	-	-	-	-	-	"	23	< 3	-
	#2 - Surface	1,500	-	-	-	-	-	"	43	< 3	-
	Depth	240	-	-	-	-	-	"	15	< 3	-
	Sediment	-	-	-	-	-	-	"	43	< 3	-
	#3 - Surface	1,200	-	-	-	-	-	"	9	< 3	-
	Depth	240	-	-	-	-	-	"	23	< 3	-
	Sediment	-	-	-	-	-	-	"	23	< 3	-
August 1	#1 - Surface	780	-	-	-	180	16	"	< 3	2	-
	Depth	180	-	-	-	-	-	"	< 3	240	-
	# 2 - Surface	6,400	-	-	-	220	24	"	4	460	-
	Depth	840	-	-	-	-	-	"	23	150	-
	#3 - Surface	2,500	-	-	-	160	8	"	9	460	-
	Depth	950	-	-	-	-	-	"	23	240	-
August 2	#1 - Surface	720	-	-	-	-	-	"	9	> 1,100	-
	Depth	84	-	-	-	-	-	"	< 3	1,100	-
	Sediment	-	-	-	-	-	-	"	< 3	< 30	-

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BASSOON LAKE

Sampling Date	Station	Total Heterotrophic Bacteria	Total Coliform	Fecal Colif.	Fecal Strep.	Yeast	Mould	Sulfate Reducers	SULFUR OXIDIZERS Thiobacillus thiooxidans	T.thioparus	Nitrifier NH_3 oxid.
Aug. 2	#2 - Surface	640	-	-	-	-	-	N.D.	< 3	> 1,100	-
	Depth	340	-	-	-	-	-	"	< 3	1,100	-
	Sediment	-	-	-	-	-	-	"	23	210	-
	#3 - Surface	760	-	-	-	-	-	"	< 3	460	-
	Depth	720	-	-	-	-	-	"	< 3	21	-
	Sediment	-	-	-	-	-	-	"	23	230	-
Aug. 28	#1 - Surface	3,600	680	< 4	-	270	6	-	-	-	< 3
	Depth	9,200	4	< 4	-	480	< 2	-	-	-	< 3
	Sediment	> 150×10^4	-	-	-	< 10	500	-	-	-	< 30
	#2 - Surface	1,800	720	< 4	-	15	< 2	-	-	-	-
	Depth	4,900	12	< 4	-	4	4	-	-	-	-
	Sediment	45×10^4	-	-	-	< 10	800	-	-	-	-
	#3 - Surface	6,400	400	< 4	-	260	12	-	-	-	-
	Depth	3,400	24	< 4	-	14	< 2	-	-	-	-
	Sediment	24×10^4	-	-	-	< 10	500	-	-	-	-
Oct. 12	#1 - Surface	870	28	< 4	< 4	52	16	< 3	4	4	< 3
	Depth	400	4	< 4	< 4	24	2	< 3	< 3	4	-
	Sediment	3,100	< 100	< 100	< 100	2	8	< 3	190	230	< 3
	#2 - Surface	540	24	< 4	< 4	28	16	9	9	4	< 3
	Depth	410	< 4	< 4	< 4	18	2	< 3	7	4	-
	Sediment	2,700	< 100	< 100	< 100	2	14	< 3	750	430	< 3
Nov. 7	# 2 - Surface	3,200	-	-	-	18	28	23	< 3	4	-
	Depth	880	-	-	-	6	12	4	< 3	4	-
	Sediment	-	-	-	-	4	30	-	-	-	-

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